8-2021

UHT Milk: Supply Chain Based Shelf Life Assessment and Risk Mitigation

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To the Graduate Council:

I am submitting herewith a thesis written by Sagar Rameshwar Padghan entitled "UHT Milk: Supply Chain Based Shelf Life Assessment and Risk Mitigation." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Industrial Engineering.

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“UHT Milk: Supply Chain Based Shelf Life Assessment and Risk Mitigation”

A Thesis Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Sagar Rameshwar Padghan
August 2021

ACKNOWLEDGEMENTS

I'd like to express my gratitude to my advisor Dr. Rapinder Sawhney, Dr. Ninad Pradhan, Dr. Vinay Mannam and Dr. Enrique Macias de Anda for their support, guidance, and encouragement throughout the duration of my research. I would also like to thank my committee members Dr. John Kobza and Dr. Jiajia Chen for giving their valuable feedbacks on this thesis.

Special Thanks to my grandfather Tejrao Sampat Padghan, my grandmother Shashikala Tejrao Padghan, my father Rameshwar Tejrao Padghan, my mother Sangita Rameshwar Padghan, my sister Sayli Rameshwar Padghan, my cousin Swapnil Mapari and Sachin Padghan and my friends for supporting me through my whole master's journey.

ABSTRACT

Transportation and storage conditions in the perishable food supply chain play a vital role in product shelf life. This study focuses on UHT milk, a variant of milk that has a shelf life of up to 12 months in ideal conditions. However, poor transportation and storage practices can diminish its shelf life and result in quality losses resulting from milk spoilage. UHT milk literature focuses on chemical and physical analysis of changes in milk. There have been limited number of studies that characterize supply chain effects on the shelf life of milk and other perishable products.

This study analyzes supply chain effects on UHT milk shelf life using four methods: 1. Accelerated shelf life study of UHT milk spoilage factors, 2. Physical simulations of supply chain scenarios, 3. Predictive model for UHT milk degradation, and 4. Supply chain planning software for managers. The accelerated shelf life study quantifies changes in UHT milk using color (L*, a* and b*), enzymatic activity (lipase and protease) and pH at varying temperatures (70°F, 80°F, 90°F and 100°F) and constant relative humidity (60%) over a period of 88 days. It is observed that a* color value provided the best correlation coefficient to quantify milk degradation. Physical simulations are designed based on actual supply chain conditions of UHT milk. The a* color value for UHT milk samples is measured at the start and end of each scenario. An iterative piecewise linear model predicts the end value of a* based on parameters from the accelerated shelf life analysis. The accuracy of the predictive model is 88%. A graphical user interface (GUI) software is designed to simplify planning the supply chain timeline of the UHT milk using the predictive model.

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CHAPTER ONE
INTRODUCTION

1.1 Background

Food waste is a worldwide problem. Approximately one-third of food produced globally is wasted or lost, which is a total of 1.3 billion tons of food annually [1]. 40 Percent of food gets wasted and spoiled annually in the United States of America, which is worth $162 billion [2]. Food loss is primarily separated into five different types [3]: 1. Storage Losses - Food loss because of improper storage, 2. Preparation losses - Food loss while preparing and cooking. 3. Serving losses - Food loss because of the leftovers on serving dishes. 4. Plate waste - Food loss because of the leftover on the plates. 5. Leftovers - Food loss because of the prepared food never served.

Improper storage holds a large proportion of food loss or food waste. The shelf life of each food item is different, and it is highly influenced by the method using which an item is stored. Storage temperature, exposure to oxygen, exposure to moisture and storage container are important factors of food shelf life. Perishable food spoils very rapidly when it is stored in indecorous storage conditions. Food waste is mainly categorized into vegetables, dairy products, meat/poultry/fish, grain products, fruits, and others [4].

Dairy products are a major category in food waste and food loss. Every year almost 116 million tons of dairy products are wasted, which is 16 percent of the global dairy production [5]. Per year, nearly 60 million tons of dairy products are wasted by distributors, retailers, consumers, and around 55 million tons of dairy products lost due to waste and spoilage at the farm and during distribution and transportation. In dairy products, milk accounts for a large percentage of food waste. Globally each year, one in six pints of milk gets wasted.

The life of raw milk is short (2-3 days) because it contains bacteria. In the last few decades, there have been different techniques developed to extend the life of milk. The following are various types of processes to extend the milk life [6]: 1. Pasteurized processing. 2. Filtered processing. 3. Ultra-high temperature processing. 4. Frozen processing. 5. Evaporated/Condensed processing. 6. Dried processing. Of these, ultra-high temperature (UHT) milk has the highest shelf life. The shelf life of UHT milk is 12 months at the ambient temperature. UHT processing technology sterilizes milk by heating it above 135°C (275°F) for 2 to 5 seconds, killing spores in milk. UHT is also called Ultra-heat treatment or ultra-pasteurization. In the UHT process, the sterilization phase eradicates all microorganisms, including bacteria, spores, viruses, and fungi, and increases milk shelf life. The UHT milk market is rapidly increasing in developing and developed regions. UHT milk can be stored at room temperature; hence it is beneficial for the countries where access to refrigeration and electricity are significant issues [7].

Worldwide, UHT milk consumption volume has increased at a compound annual rate of growth (CARG) of 5.9% from 2011-2018 [8]. In 2019, UHT milk consumption volume was 116.38 billion liters. According to market analysts, it will reach a volume of 163.23 billion liters by 2025 [9]. In Korea, from 2017 to 2018, UHT milk sales increased by 46.3% [10]. In the UHT milk market, Europe held a leading 40.5% share of the global revenue in 2018. The high demand for UHT milk in European countries is because of the substantial evolution of dairy products. Germany, Holland, and Belgium are the top three countries from Europe in UHT milk consumption. In the Asia Pacific, it is anticipated that the UHT milk market will increase at a compound annual rate of growth (CARG) of 9.1% over the period of 2019 to 2025 because of the high consumption of milk products in countries like India, Japan, and China[7]. UHT milk is divided into flavored and unflavored products. In 2018, unflavored UHT milk dominated the market by accounting for 77.8% of the total share [7]. Unflavored UHT milk products are daily use products and can be used as raw material for homemade products; hence they have a large customer base.

There are five factors which directly affect the shelf life of UHT milk [11] 1. Quality of raw milk, 2. UHT process, 3. Transportation conditions, 4. Storage conditions, and 5. Types of packaging. In the United States, the Food and Drug Administration (FDA) enforces strict regulatory guidelines for UHT milk production. Hence, there are minimal chances of UHT milk spoilage because of raw milk quality, UHT process, and aseptic packaging. Transportation conditions and storage conditions have a significant impact on the stability of UHT milk. Temperatures below 20˚C (68˚F) are favorable for the long shelf life of the UHT milk. When the UHT milk storage temperature increases, the UHT milk shelf life decreases [11].

Accelerated shelf-life studies were conducted to analyze storage condition effects on UHT milk shelf life. Room temperature and elevated temperature were used in the studies. Elevated temperature accelerates the deterioration rate of the UHT milk. The accelerated shelf-life study also explains various attributes that show significant changes during the elevated temperature. In most shelf-life studies, four to five different temperatures were selected from room temperature and elevated temperature for shelf life analysis. But there is limited literature available of shelf-life study of UHT milk on actual supply chain conditions. In prior research, shelf life of perishable food increased by different tools such as intelligent food logistics, supply chain management like first-expired-first-out (FEFO), etc. Hence, there is a need to analyze and enhance the shelf life study using the existing supply chain conditions.

1.2 Problem Statement

This research focuses on identifying factors that affect UHT milk shelf life and developing a model to predict the degradation rate of UHT milk based on supply chain conditions. The areas of research are:

- A shelf life study that compares the spoilage characteristics for common parameters (color, pH, enzyme activity) for UHT milk has not been reported in literature. This comparison helps identify the most suitable parameter to characterize UHT milk spoilage in supply chain conditions.

- Supply chain conditions impact degradation and spoilage rates for UHT milk. However, shelf life analysis literature uses highly constrained experimental plans for UHT milk, with no reported experiments that emulate realistic supply chain conditions.
- There is no predictive model for remaining shelf life for UHT milk given supply chain conditions.
- There is no software interface reported in literature to help supply chain managers plan the transportation and storage conditions for UHT milk to reduce quality degradation.

1.3 Approach

The approach of the thesis is mainly divided into five phases, shown in Figure 1.

1.3.1 Phase 1

This phase contains a comprehensive literature survey on the following factors: 1. UHT process, 2. Historical Development of UHT milk, 3. UHT milk shelf life study, 4. Supply chain analysis of perishable food, and 5. UHT milk supply chain analysis. It identifies the various factors which affect the shelf life of the UHT milk.

1.3.2 Phase 2

The accelerated shelf-life study is conducted to understand the impact of environmental conditions on UHT milk shelf life. This study was conducted using temperature, the environmental factor with the highest reported impact on UHT milk shelf life. Four different temperatures 70°F, 80°F, 90°F, and 100°F, were selected in the accelerated shelf-life study, and the relative humidity kept constant at 60% for each temperature variation. The accelerated shelf-life study was conducted for 88 days, and at 0, 12, 25, 32, 39, 46, 53, 60, 67, 74, and 88 days

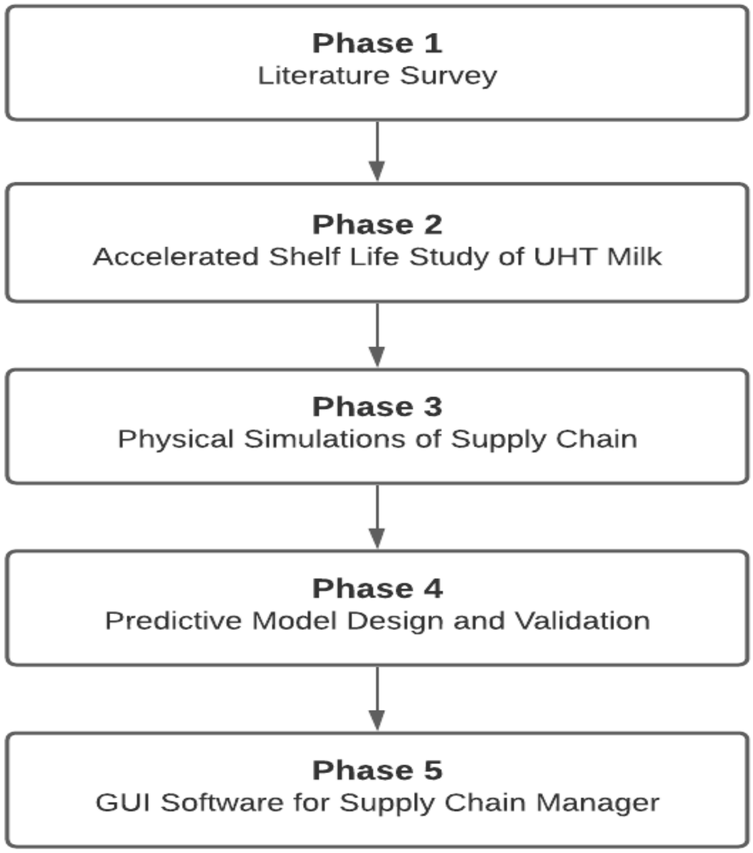

Figure 1: Approach

UHT milk at each temperature was sampled for analysis. Four parameters, pH, lipase activity, protease activity, and color in L, a, b values were considered for the analysis.

1.3.3 Phase 3

The physical simulation is designed based on the activities at the supply chain's receiving and storage facilities. In this phase, two different physical simulations of the supply chain were conducted. First, physical simulation scenarios were designed based on 70°F, 80°F, 90°F, and 100°F temperature values, which were used in the accelerated shelf-life study. The second physical simulation scenarios were designed based on the actual temperature obtained from historical data, and the temperature changed every 3-6 hours. Weather Underground [12] and NOAA websites were used for the historical data collection. At the start of the experiment, the baseline color value was measured for the UHT milk. Following this, physical simulation scenarios were conducted using a climate control chamber. Relative humidity was kept at 60%. At the end of the experiment, the UHT milk's color values were measured for each scenario.

1.3.4 Phase 4

An iterative piecewise linear model was developed to estimate the change in the color of the UHT milk. Parameters for the model were obtained from the accelerated shelf life analysis. The predictive model required three inputs, baseline color value, temperature, and duration of the supply chain at each node. The model predicts the color value of the UHT milk based on these inputs. The predictive model values were compared with the actual values obtained from the physical simulation scenarios to calculate the model's accuracy.

1.3.5 Phase 5

Graphical User Interface (GUI) is designed to predict the shelf life of the UHT milk in the supply chain. This GUI allows the user to enter the UHT milk's location, duration, and storage conditions in the supply chain and calculates UHT milk spoilage risk. The planner or manager of the UHT milk can review the effects of the supply chain conditions on the UHT milk spoilage risk and make appropriate changes to the plan to improve the shelf life.

1.4 Scope and Limitations

This thesis has the following scope:

- The iterative piecewise linear model can be applied to all unflavored UHT milk brands to estimate the UHT milk shelf life, whenever spoilage parameters are known or have been measured.
- The developed iterative piecewise linear model will help the supply chain manager or planner of the UHT milk to predict the spoilage risk in the supply chain.
- The predictive model can be used to improve supply chain conditions and decrease the risk to planned shelf life.

This thesis has the following limitations:

- An accelerated shelf-life study was conducted and analyzed on whole UHT milk, so it is uncertain that this model will work for other UHT milk such as non-fat, reduced-fat, flavored, or chocolate UHT milk.
- This study has not characterized "spoilage" in sensory terms in this study. Sensory analysis used to analyze, measure, evoke and interpret reactions on food by the smell, touch, taste, senses of sight and hearing.

1.5 Organization of the Thesis

The given thesis is written into five chapters. The first chapter has provided the overall picture of the thesis. The second chapter contains a thorough literature search about the UHT process and current accelerated shelf-life study. It also includes the research of the supply chain of the perishable food and UHT milk and factors that affect UHT milk's shelf life. The third chapter is a methodology that explains how the accelerated shelf-life study of UHT milk was conducted, development of the physical simulation of supply chain scenarios, design of the predictive model, and GUI software for supply chain managers. The fourth chapter are the results and it compares the actual values from physical simulation and predicted values from an iterative piecewise linear model. It also includes the analysis of accelerated shelf-life study. The fifth chapter provides the conclusion of the research with research limitations and future work.

CHAPTER TWO
LITERATURE REVIEW

2.1 Systematic Literature Review

This chapter reviews the existing work about UHT milk and the supply chain of food. Surveyed research papers and books related to UHT milk production techniques, shelf-life study, and supply chain analysis of perishable food using Google Scholar, Google Books, Science.gov, ResearchGate, IEEE Xplore, and Science Direct.

The following keywords for each of the categories were used. For the UHT process, the keywords were "UHT milk," "milk heat treatment," "pasteurization methods," "flash heating and cooling," "aseptic packaging." The subsequent section of the literature review is the UHT milk shelf-life study, and the following keywords were used: "milk shelf life study," "UHT milk shelf life study," "accelerated shelf-life study," "chemical and physical changes in UHT milk" and "Maillard reaction." The next sections are food supply chain and UHT milk supply chain. Keywords were "supply chain," "supply chain management," "value supply chain," "food supply chain," "food loss," "food waste," "abiotic conditions and biotic conditions," "dairy supply chain," "UHT milk supply chain" and "the role of information technology in the food supply chain." The search range was restricted between 2000 to 2020 for supply chain analysis of food and dairy supply chain analysis.

Approximately 10,000 to 12,000 research papers from each of these areas were found. These results were filtered using keywords like UHT milk, perishable food supply chain, and UHT process. Therefore, a total of 52 papers were included in this study.

2.2 UHT Process

UHT milk is also called Ultra-heat treatment milk or ultra-pasteurization milk[13]. UHT process is commonly used in milk production, but the process is also used for yogurt, honey, cream, fruit juices, wine, and stews[14]. UHT processing technology sterilizes milk by heating it above 135 °C (275 °F) for 2 to 5 seconds, killing spores, bacteria, and microorganisms in milk. In the UHT process, milk is sterilized before packaging and then filled into pre-sterilized containers in a sterile atmosphere. Milk passes through heating and cooling stages in quick succession, and aseptic filling helps to avoid reinfection in the milk. The step by step procedure to convert raw milk into UHT milk using the UHT process is as shown in Figure 2. UHT process is primarily categorized into four steps [15, 16]: 1. Flash heating, 2. Flash cooling, 3. Homogenization, 4. Aseptic Packaging.

In the flash heating process, the milk is preheated to a noncritical temperature (between 70-80 °C), and then it is quickly heated for a few seconds at a high temperature (above 135 °C). The Flash heating process can be done using direct heating systems and indirect heating systems. The primary purpose of flash heating is to uphold the high milk temperature for a short time and to confirm that the temperature is evenly circulated throughout [16].

Direct Heating Systems – The milk will be in direct contact with the hot steam in the direct heating system. Direct heating can be done in two ways: the injection method and the infusion method. In the injection process, high-pressure steam is injected into the milk. It helps for rapid heating and cooling. The second process is an infusion, where the milk is pumped into the chamber using a nozzle with high-pressure steam. In this method, the milk temperature is accurately controlled via pressure. That's why there is no risk of burn on or localized overheating. This method is suitable for high and low viscosity liquid [16].

Indirect Heating Systems - In the indirect heating system, liquid and heating medium are separated by the apparatuses. After the heating process, the liquid enters a vacuum chamber where it quickly loses temperature. This process

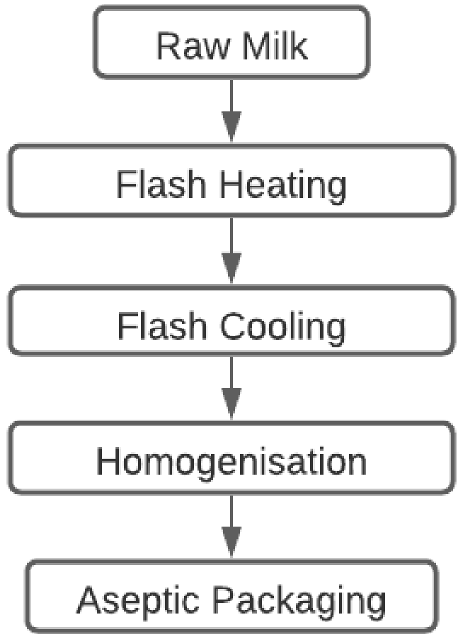

Figure 2: Step by step UHT milk processing [15, 16]

reduces the risk of thermal damage. Indirect heating systems mainly use three types of exchangers: plate exchangers, tubular exchangers, and scraped-surface exchangers[16].

Flash cooling is a subsequent flash heating step, where milk is passed through a holding tube and then to a vacuum chamber. The flash cooling's primary purpose is to remove the volatile component and excess water due to steam contact. Flash cooling also helps to lower the hazard of thermal damage[16].

The homogenization process does not require any additive, and it is a mechanical process. The homogenization process specifically breaks down large fat molecules into smaller sized molecules in milk and increases the fat globules' total surface area. In raw milk, the layer of cream forms as the fat molecules increase. The homogenization process prevents milk from breaking the molecules into petite sizes and keeping milk in the original size. Homogenization is very important in the UHT process for a longer shelf life[17].

The aseptic packaging process thermally sterilized the milk and inserted it into the previously sterilized container in a sterile environment. This process abolishes the entry of the microorganisms/bacteria into the package.

Excessive heat treatment changes the flavor of milk to a cooked taste, while insufficient heat treatment increases microorganisms in the UHT milk. Hence, the type of heat treatment, pre-treatment conditions, time-temperature range, and aseptic packing of the UHT process defines the UHT milk's quality and shelf life.

The usage of UHT milk differs from country to country. European countries like Germany, France, Italy, and Spain have the highest numbers of UHT milk consumption and usage. According to the study of 'Arla Foods'[2], UHT sales increased by 100 percent in the last thirty years in the Western European market, while UHT milk accounts for more than half of all milk sales. Countries with strong dairy culture, such as Germany, using two out of every three liters of UHT milk.

In the last few years, UHT milk is higher in demand in developing countries of the Middle East, Africa Asia-Pacific. Countries like India and China are moving towards products that have a longer shelf life. In China, the consumption of UHT milk is approximately 60 percent of the total milk consumed. UHT milk consumption is increasing significantly in Australia, which was only 10 percent in 2012.

2.3 UHT Milk Shelf Life Study

The shelf life of the UHT milk is nine to twelve months at ambient temperature if unopened. Shelf life is defined as the period of time for which goods remain acceptable to consume and retain its physical, chemical, sensory, and microbiological features when stored in suggested conditions [18, 19]. Food spoilage is one of the main problems for the food industries, supplier, and customer. A shelf life study helps to understand the significant factors of the product such as quality of product with respect to time, storage variability as well as to discover the ideal shelf life of the product. There are two different ways to do a shelf life study of a product [20]: 1) Real-Time Shelf Life Study and 2) Accelerated Shelf Life Study.

In the real-time shelf study, the product is exposed to recommended storage conditions and supervised until it fails the specifications [21]. Real-time shelf life study of the UHT milk can take up to 12 months; that's why it is time-consuming and costly. An accelerated shelf-life study is very effective in such scenarios with a significant reduction of time and cost [22]. In the accelerated shelf-life study, the product is exposed to elevated storage and transportation conditions like temperature, humidity, etc. [22, 23]. This process helps to accelerate the deterioration rate of the product and predict the shelf life. The accelerated shelf-life study is mainly useful for stable ambient products which have long shelf lives. The accelerated shelf-life study is primarily conducted to predict shelf life, exploitation testing of goods, estimation of product stability in less time, and troubleshooting variability problems [24].

Temperature is the most used acceleration factor in the accelerated shelf-life study of perishable goods because of the relationship with the deterioration rate, which is defined by the Arrhenius equation [21]. Arrhenius equation is commonly used to evaluate the effect of storage temperature on the rate of chemical reactions. Arrhenius equation explains the correlation between absolute temperature and velocity constant. Velocity constant means the rate constant of a chemical reaction[25, 26].

In the shelf life study, knowledge of all the quality attributes which change during storage and transportation is required. Based on quality attributes, the main quality factors which limit the shelf life of the goods need to be recognized [24].

2.3.1 Accelerated Shelf Life Study of UHT Milk

In the past, studies have been done on the accelerated shelf life of UHT milk with different focuses such as sensory attribution, Maillard reaction, proteolysis, and many more. Chemical and physical changes start occurring in the UHT milk right after the UHT process. Maillard, proteolytic, oxidative, and lipolytic are the most common reactions that occur in UHT milk during storage[27].

In 2014, the shelf life study was conducted on low-fat UHT milk of a specific brand [22]. This study mainly focused on determining the shelf life of the low-fat UHT milk with the multivariate accelerated shelf life test and finding the attributes that will be used as predictors for the end of shelf life. There were three different temperatures used for the shelf life study. 1) normal temperature - 25°C and 2) elevated temperature - 35°C and 45°C. The elevated temperature is used as an accelerating factor to increase the deterioration in the milk. High-density polyethylene bottles were used to store the milk. The sensory evaluation conducted on the UHT milk for 18 different attributes cooked aroma, overall milk aroma, fresh milk aroma, glass coating, the extent of optical thickness, viscosity, fat feel, mouth-coating, dry/chalk feel, creamy flavor, overall milk flavor, sweet taste flavor, off-flavor, cooked flavor, fatty aftertaste, metallic, sweet and dry/chalk aftertaste. UHT milk storage for a longer period of time at higher temperatures had higher intensity of off-flavor, cooked flavor, metallic flavor, dry/chalk feel, and dry/chalk aftertaste. While there were no significant changes in the cooked aroma, mouth-coating, fat feel, glass coating, fatty aftertaste, and viscosity. From the microbiological quality perspective, there was no significant increase in aerobic spores. A non-linear regression method used to calculate multivariate parameters, and from that, the shelf life of the low-fat UHT milk was predicted. The low-fat UHT milk's shelf life predicted 211 (±7) days when it was stored at a normal temperature of 25°C. The experiment results clearly explained that as the storage temperature increases, the UHT milk's shelf life decreases. The low-fat UHT milk's shelf life was reduced to 73(±3) days and 27 (±1) days at elevated temperatures of 35°C and 45°C, respectively. The sensory deterioration rate of the low-fat UHT milk will be 2.89 times faster at 35°C and 7.83 times faster at 45°C than the sensory deterioration at 25°C.

In 2016, an accelerated shelf-life study was conducted on a full fat and skimmed UHT milk from 'Arla Foods' Germany[28]. The goal was to measure chemical and physical changes with different storage conditions and develop strategies or setup to speed up shelf life development. Full fat and skimmed UHT milk were exposed to slightly cooled, normal, and raised storage temperatures (10°C, 20°C, 30°C, 40°C, and 50°C) and three temperature cycles for the duration of 24 weeks. For all the storage temperatures according to their reaction rate, 3-12 analysis points were selected. The analyzing method for UHT milk's accelerated shelf life were high-pressure liquid chromatography (HPLC), liquid chromatography-mass spectrometry (LC-MS), turbiscan, colorimeter, microplate reader, milkosscan, lumifuge, and master sizer. Enzymatic and non-enzymatic browning reactions are responsible for the color changes in food. If food is heat-treated, then only non-enzymatic browning reactions occur, and non-enzymatic browning reactions occur due to Maillard reaction or caramelization[29, 30]. A Chroma meter was used to measure the color changes for both full fat and skimmed UHT milk, and the results show a linear trend in changing color for the 24 weeks of the storage period. There was a substantial reduction of lightness (L*) in both UHT milks stored between 20°C and 50°C. Furthermore, substantial increase of green to red (a*) and blue to yellow (b*) in both UHT milks stored between 30°C and 50°C[28].

In the Maillard reaction, amino acid and reducing sugar chemical react to each other and produce browned food, which is a distinctive flavor[31]. Maillard reaction is also responsible for changes in flavor and odor of the UHT milk. Maillard reactions mainly occur during long term storage at elevated temperatures. The Maillard reaction rate increases as the thermal process's duration, temperature, and pH increase [29]. High-pressure liquid chromatography delivers fast and precise analysis of proteins and peptides from different biological or synthetic sources [32].

The UHT milk shelf life study section explicitly described the effect of room temperature and elevated temperature on the UHT milk. Off-flavor, cooked flavor, enzyme activities, and color attributes are affected due to the higher storage temperature of UHT milk.

2.4 Food Supply Chain

Supply chain conditions of UHT milk directly impacts the shelf life of the UHT milk. Improper supply chain conditions reduce the shelf life of the UHT milk very rapidly. The complete process of manufacturing and selling commercial products is called a supply chain[33]. In other words, the supply chain is the process which includes moving and converting the raw materials into finished goods and shipping those products to the distributor then on to the final customer. The supply chain consists of manufacturers, warehouses, transportation, vendors, retailers, and distribution centers. Supply chain management helps optimize the product’s supply chain to lower the overall cost, increase the production cycle rate, and increase the profitability of the company [34]. Food supply chain is defined as effectively and safely delivering food goods from farmed crops to customer forks. The food supply chain's biggest challenge is to maintain high standards of quality and safety of food products throughout the supply chain for the customer because of short shelf life, perishability, and quality decay properties of food [35].

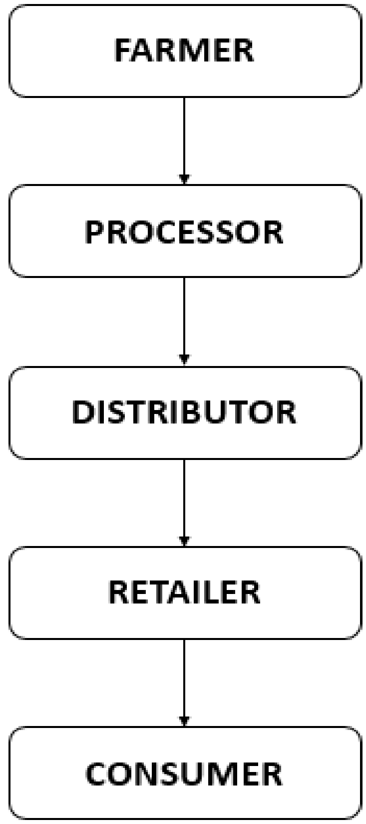

Figure 3: Basic food supply chain of food movement [36]

The demand for the food supply chain is mainly influenced by the supply side and customer demand side. Plants and animals primarily obtain food, and it is connected to human and environmental factors; that's why food production is a volatile and uncontrollable natural phenomena[37]. Food has to sustain in abiotic conditions and biotic conditions[38].

Food loss and food waste are major concerns in the food supply chain, directly affecting food sustainability. Food getting spoiled, spilled, lost, or decreasing in the quality during the food supply chain process before it reaches customers is called food loss. Food waste completes the food supply chain process until final customers but still gets discarded due to expire or spoilage[39].

The food transportation system is the backbone of the food supply chain. It is expected that the transportation system should maintain the food temperature condition using different devices to increase sustainability. Controlling the food temperature may increase the product's cost, but it will significantly increase its shelf life and reduce food loss and food waste. Most of the countries transport perishable food using mechanically refrigerated vehicles or containers[40].

Globalization, customer tastes and lifestyles, market structure and power, technological changes, and regulation forces significantly impact the food supply chain development[41]. The evolution of the food supply chain is divided into four phases [42]. 1. Domination of regional wholesalers in the food supply chain, 2. domination of national manufactures in the food supply chain, 3. food manufacturers expanded the business internationally, and 4. globalization phase dominated by retailers. After 2,000, food retailers became an essential part of the food supply chain. They are responsible for collecting goods from the manufacture's gate and delivering to consumers.

Communication and information technology (IT) are the most important factors in the food supply chain. IT plays a vital role in connecting internal processes to external providers and consumers. Electronic data interchange helps to share information and improve the existing business processes and activities. Radio frequency identification technology is like barcode technology. It is simple in terms of architecture and function. Radio frequency identification technology tracks the goods, and it consists of an RFID tag, an RFID reader device, and IT system[43].

2.5 UHT Milk Supply Chain

An effective dairy supply chain is the key to success in the dairy industry. Temperature, humidity, time, forecasting, cost, demand, distance, and packing are vital considerations in creating a solid dairy supply chain [44].

The first step of the UHT milk dairy supply chain is collecting milk from cows in a cooling storage tank via pipes[44]. UHT Milk remains stored in a cooling storage tank for less than 48 hours, and the cooling storage tank temperature is below 40^{0}C. In the next step, trucks pick up milk and transport to the dairy industry. After that, UHT milk gets tested to confirm the quality of milk, if the quality of UHT milk is good, it gets processed; otherwise, it is discarded. In the dairy industry, UHT milk goes through all the UHT processes and then gets shipped to retailers in temperature-controlled trucks.

The quantity of milk cows produce differs from session to session. Naturally, the production of milk from cows increases by 10 to 15 percent in the spring. Due to such variations, dairy industries experience shortages or excess of raw milk. In the dairy supply chain, milk is transported by temperature-controlled trucks instead of faster and more costly transportation modes because of its weight. Resilience is essential in dairy industries to eliminate transportation and storage disruptions.

RFID (Radio-frequency identification) tags are used to track the cow or buffalo's health and eating and resting activities. RFID tags provide signals like cold body temperature and low activity, which helps to identify the health of the cow [44].

Legislature is one of the reasons for the complexity of the dairy product supply chain. In the United States, 91,000 pounds of milk is allowed per truck, and trucks should have a sixth axle. While in Canada and Europe, 100,000 pounds is allowed per truck. An increase in the weight limit helps to minimize the transportation cost of trucks on the road[44]. According to the California Legislative department, UHT

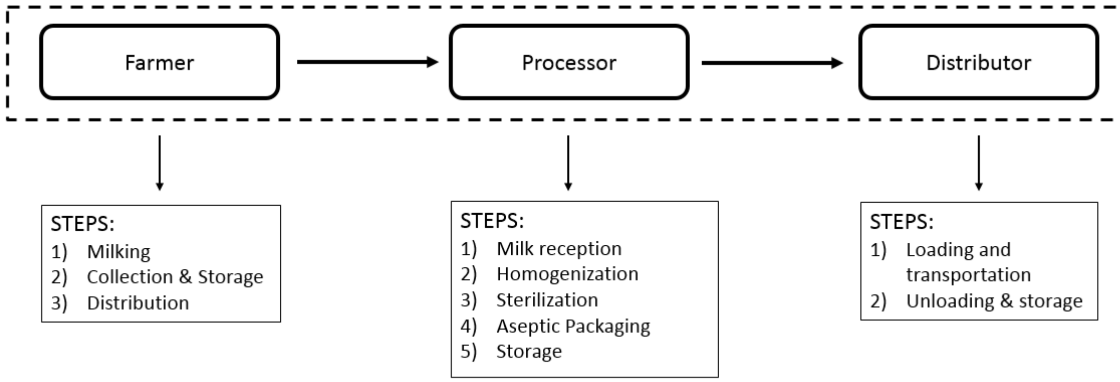

Figure 4: Simplified UHT milk supply chain and it's characteristics [45].

milk should contain more than 3.25 percent milkfat and 8.25 percent milk solids-not-fat[46]. UHT milk production rules differ from country to country and affect the supply chain of UHT milk.

CHAPTER THREE
METHODOLOGY

The shelf life of a perishable product depends on several conditions from the supply chain, for example: process variables, transportation conditions, storage conditions, and types of packing. It has been found that temperature and humidity are major variables in shelf life stability of perishable products - the higher the temperature, typically the lower the shelf life [11]. Therefore, there is a need to understand the chemical and physical changes of perishable products with respect to temperature and time. This information is generated using accelerated shelf-life studies, which identify the factors relevant to spoilage of the specific product. The methodology to achieve this prediction begins with accelerated shelf-life studies, which identify the factors relevant to spoilage of a specific product. These spoilage factors are modeled in a physical simulation to emulate realistic supply chain conditions. The predictive model is validated using parameters from the accelerated shelf-life study and data from the physical simulation. The supply chain manager is provided with an intuitive interface to use the predictive model in estimating the remaining shelf-life of their product. The product chosen in this methodology is UHT milk because it has the highest shelf life of all the milk products and experimental protocol for accelerated shelf life study are designed depending on the shelf life of the milk product. The methodology for UHT milk shelf life analysis is shown in Figure 5.

3.1 Accelerated Shelf Life Study

The accelerated shelf-life study examines the chemical and physical changes in UHT milk at different climate conditions. UHT Milk was exposed to different temperatures with a climate control chamber in the accelerated shelf-life study. This method accelerates the deterioration rate of the product using elevated temperature conditions [22]. Maillard reaction is a primary reason for chemical

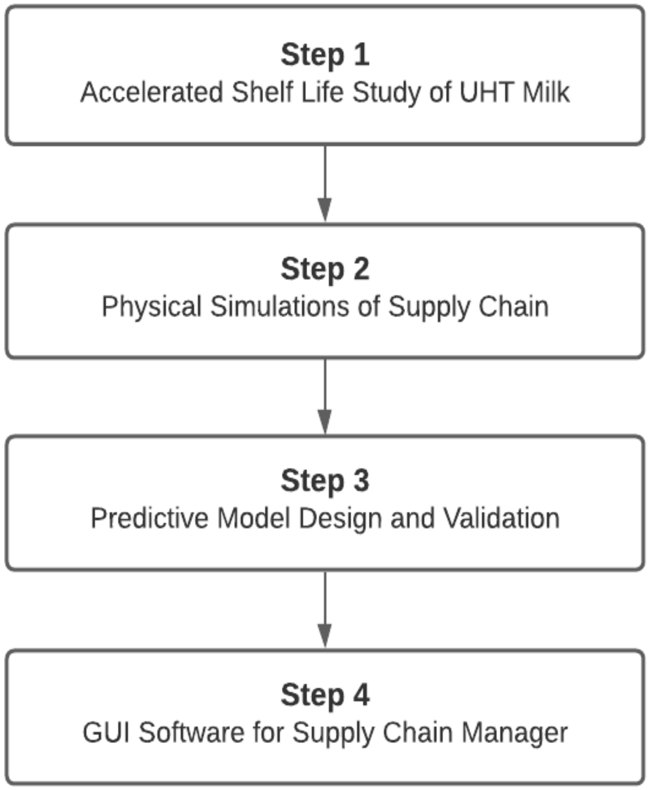

Figure 5: Methodology Approach

changes in milk. The Maillard reaction takes place between reducing sugars and free amino acids and peptides during heating [31]. Various parameters may be considered for accelerated shelf life analysis of UHT milk, including [22]: aroma, the extent of optical thickness, color, viscosity, fat feel, mouth-coating, flavor, cooked flavor, fatty aftertaste, metallic, pH, etc. Previous studies have shown [22, 28] that the four parameters which show the greatest change during a shelf life study are pH, lipase activity, protease activity, and L*, a*, b* color value. Therefore, the subsequent steps in the methodology are explained for these four parameters.

3.1.1 Experimental Strategy

It is essential to consider the composition of UHT milk to be able to accurately study its spoilage under accelerated conditions. The composition of UHT milk is determined by factors such as total fat content, cholesterol, sodium, potassium, and total carbohydrates. Temperatures to which the UHT milk is exposed are selected from a range that varies from ideal to extreme [28] which is between 60°F to 110°F with a gap of 5°F to 10°F. Typically, four to eight different temperatures are selected in the design of milk study protocols. Climate control chambers are used in the experiments. They are kept in ideal conditions for a stabilization period trial run and to check the chamber's stability. After that, climate control chambers are set to temperatures with a gap of 5°F to 10°F. Experiments are conducted and the UHT milk is sampled for pH, lipase activity, protease activity, and L*, a*, and b* color values with an interval of standard time. Internal sampling times vary from product to product. In the previous UHT milk accelerated shelf life study the sampling time interval was between 7 to 10 days. Then the results of the samples are analyzed to determine: 1. Is there a uniformly increasing or decreasing trend in the parameter data for normal to extreme temperatures? 2. Is there a clear separation between the curves for normal to extreme temperatures?

3.1.2 Analysis of Lipase Activity

The lipase activity of milk was analyzed according to the method of Humbert et al. [47, 48]. The milk sample (0.5 mL) was mixed with 2 mL 0.05 M barbital buffer with pH 7.6 in a test tube. Then substrate (0.05 ml 50 mM nitrophenyl butyrate in acetonitrile) was added to the mixture, which was mixed and stored at 37°C for 10 min. Then 0.4 ml inhibiting solution (three volumes 0.06 M EDTA adjusted to pH 7.6 with 2 M NaOH plus one volume 0.06 M phenylmethanesulphonyl fluoride in dimethyl-formamide) and 2 ml clarifying reagent was added to the sample, which was mixed and stored at 37°C for 3 mins. Then the mixture was transferred to a cuvette, and the absorbance was determined at 420 nm by a spectrophotometer at the same time after heating. The blank contained 2 mL 0.05 M barbital buffer of pH 7.6, 0.5 mL distilled water, and 0.05 ml 50 mM nitrophenyl butyrate. Different concentrations of nitrophenol are used to set up a standard curve. The milk sample's lipase activity is expressed as µmol nitrophenol produced per minute per ml of milk.

3.1.3 Analysis of Protease Activity of Milk

Protease activity of milk was determined as follows [49-51]: 0.2 mL milk was added to 2 mL 1% sulphanilamide azocasein solution in 50 mM 3-(N-morpholino) propansulfonic acid (MOPS, pH 7.2) containing 1 mM $CaCl_2$. The mixture was stored in a water bath at 35.5°C for 15 min. The reaction was stopped by adding 4 ml 5% trichloroacetic acid. The sample was filtered through Whatmann 2 paper, and the absorbance of the filtration was determined at 345 nm by a spectrophotometer. For blank, 0.2 mL distilled water, instead of milk, was used. The protease activity was expressed as absorption increased at 345 nm per minute per ml of milk.

3.1.4 Analysis of pH of the Milk

The pH of milk was calculated at the same temperature using an Oakton pHTestr 30 Waterproof Pocket Tester. First, an electrode of the pHTestr 30 was immersed in electrode storage solution for 30 minutes before use. Then the electrode was placed 2-3 cm deep into the pH buffer solution for 2 minutes to confirm the calibration point. Then the electrode is rinsed with tap water before measuring the pH of the milk. Then the electrode is placed 2-3 cm deep into milk, stirred gently for reading stabilization, and then the pH value is recorded from the pHTestr 30 screens. After each reading, the electrode was rinsed with tap water and the above steps were followed to calculate the pH of other samples.

3.1.5 Analysis of Milk Color

The milk was weighed in a container, and Hunter LabScan colorimeter is used for analysis. L* (luminosity or lightness), a* (green-red component), and b* (blue-yellow component) color values of milk were measured. The lightness L* value represents the darkest black at L*= 0, and the brightest white at L*= 100. a* and b* color values represent true neutral gray values at a*= 0 and b*= 0. a* axis represents the green-red components, with green in the negative direction and red in the positive direction. The b* axis represents the blue-yellow components, with blue in the negative direction and yellow in the positive direction.

3.2 Physical Simulation of Supply Chain

When supply chain traceability data is neither directly available nor easily accessible, then physical simulation plays a vital role in data collection. The physical simulation imitates activities taking place in the supply chain. It gives a premise to control the condition of the actual product to replicate realistic conditions. Two different physical simulations of the supply chain were conducted in the study.

3.2.1 Physical Simulation

This physical simulation imitates activities taking place at the receiving and customer storage facilities of the UHT milk supply chain. At the receiving warehouse, milk is exposed to more variation in climate conditions, and customer storage may or may not have standardized storage conditions. At the same time, there are multiple reasons for not focusing on the previous segment of the supply chain. First, the UHT milk production process is carefully managed according to the Food and Drug Administration (FDA) guidelines. During milk production, milk has no human contact from the milking process to the packaging process. Hence, there are minimal chances of improper storage or contamination at production facilities. Second, it is assumed that milk transports in temperature-controlled vehicles; therefore, quality losses due to temperature during transportation are minimal.

The general process of designing the physical stimulation of milk is as mentioned. First, the activities were identified at the receiving and customer storage facilities in the supply chain from the company and interviews with receiving and storage handling employees. Then, historical data for weather was used to establish ambient conditions at receiving and customer storage nodes of the supply chain. Then multiple scenarios were designed based on the activity, duration, and temperature. There were multiple types of activities that could happen at receiving and customer storage facilities in the supply chain, such as storage of milk at the customer's warehouse and waiting for vehicle pick up of the milk. Scenarios are designed in such a way that it will reflect the normal and extreme conditions for milk storage and handling. Conditions were emulated in the lab using a climate-controlled chamber. At the start of the experiment the base value of the parameter was calculated and then at the end of the experiments final values were calculated for all scenarios.

3.3 Predictive Model Design and Validation

Four parameters, pH, lipase activity, protease activity, and color in L, a, b values, were used in the accelerated shelf-life study to analyze the UHT milk's chemical changes. From the accelerated shelf-life study, one parameter is selected based on the uniformly increasing trend of normal to extreme temperatures, and there is a clear separation between the curves for normal to extreme temperatures. Based on this result, physical simulation experiments were conducted, and the selected parameter was measured before and after the experiments. In this study the a* color value parameter is selected because it shows a uniformly increasing trend for normal to extreme temperatures, and there is a clear separation between the curves for normal to extreme temperature.

The milk color threshold of spoilage is unknown therefore we assigned an arbitrary threshold value and focused on predicting milk's remaining shelf life before it crosses the threshold. The threshold means the establishment of a limit statute, below which no regulatory action will be taken. The prediction model for remaining shelf life of milk was developed to achieve two objectives: 1. Predict the change in milk a* color value for supply chain scenarios, when given time and temperature for activities, and 2. Estimate the remaining shelf life.

The following assumptions were made in the prediction of the milk color change: 1. The baseline a* color value is known. 2. The rate of change of a* color corresponding to temperature has been estimated using shelf-life studies. 3. The rate of change of color is constant for time interval. 4. The rate of color change is independent of the baseline a* color value of the milk. Then an iterative piecewise linear model was developed to predict the a* color value of the milk at the end of the scenario. The model is shown below:

$$a_1^* = a_0^* + \beta_1 t_1$$
$$a_2^* = a_1^* + \beta_2 t_2$$
$$\vdots$$
$$a_n^* = a_{n-1}^* + \beta_n t_n$$

Where, a_0^* is the baseline a* color value of the milk common to all scenarios. This value can be determined immediately after the production of milk. β_i represents the rate of change of a* color of milk during the i^{th} activity, corresponding to the temperature at which the milk is being stored during that activity. t_i represents the duration of an activity. The iterative component of the model is evidenced by each a_i^* term using the a_{n-1}^* term as the baseline a* color value in its estimation of the changed a* color. Assumption (4) permits the use of this type of piecewise splicing. The remaining shelf life of the milk changes after it experiences less-than-ideal conditions in the supply chain. This change is predicted based on the following input variables: 1. The color value at the end of a scenario, a_n^*, is used as the baseline for the remaining shelf life prediction, 2. the rate of change of color is used to predict the future color value of the milk, 3. the color threshold value for spoilage, $a_{spoiled}^*$, is assumed to be available from sensory tests. In its absence, to demonstrate the concept, an arbitrary value is assumed, and 4. the expected remaining shelf life, $t_{expected}$, is the number of days between the date of completing the physical simulation and the printed date on the milk package.

The estimated remaining shelf life is formulated as follows,

$$t_{estimated} = min\left(\frac{a_{spoiled}^* - a_n^*}{T_k}, t_{expected}\right), k = 1, \dots, M$$

In this formulation, the fraction represents the time it will take for milk to reach the spoilage value, estimated over a range of temperatures T_k for which the rate of change of color is available. If this time value exceeds $t_{expected}$, then the milk will attain its ideal shelf life, printed on the package. The remaining shelf life indicates to a pantry or inventory manager on the customer side the effects of an ambient storage temperature T_k on the remaining shelf life of the milk, given that some color degradation has already occurred in the supply chain. It guides the development of inventory policies on the customer side.

3.4 GUI Software for Supply Chain Manager

Software User Interface (GUI) makes it easy to translate the research's technical outcomes into simplified practical tools for the user. Additionally, GUI permits user options and model outputs to be visualized.

There are four design elements of the GUI shown in Figure 6: 1. Specification of the supply chain, 2. Estimation of spoilage risk, 3. Milk color trend graph, and 4. Export plan to Excel. Specification of the supply chain is an input element of the GUI software that allows the user to enter details about the milk supply chain route. For each node of the supply chain, the user must select supply chain location, stay duration, and temperature. The GUI allows the user to choose between the four types of supply chain locations: 1. Transportation, 2. Warehouse, 3. Loading dock, 4. Customer storage. The second element is the estimation of the spoilage risk, which is an interactive element. Once we entered the supply chain route and pressed the “Estimate spoilage risk” button, the GUI software will update ‘days to spoilage,’ ‘spoilage risk,’ and ‘days to delivery’ boxes based on the prediction model. The milk color trend graph is the third design element. This graph contains the low, medium, and high spoilage risk region. It will show the spoilage risk region for the given supply chain route of the milk. It will help the user to identify the supply chain node where the risk of spoilage increases. This gives the supply chain planner/manager a chance to make changes to the supply chain route of milk,

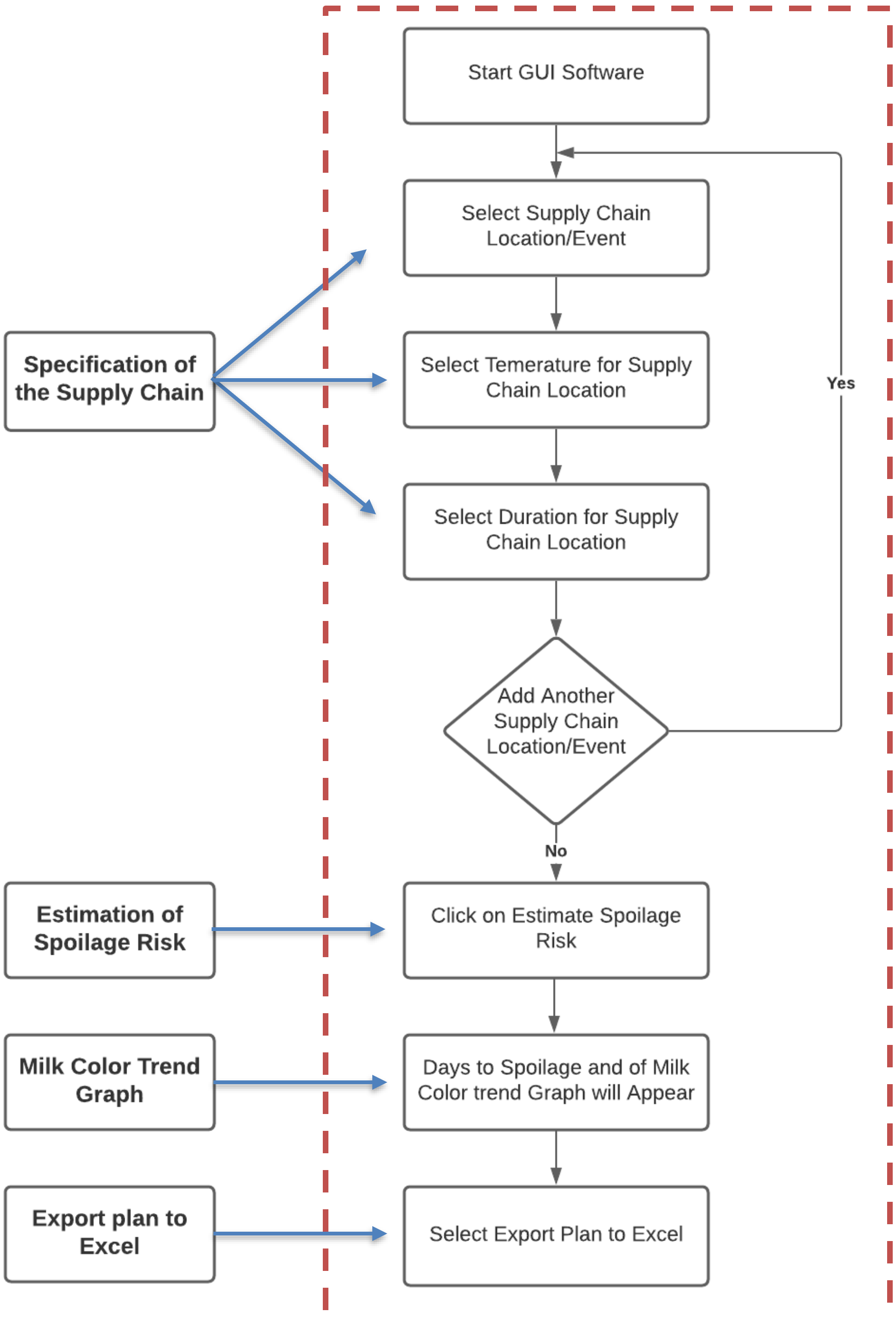

Figure 6: Interactions for the GUI Software

which improves the shelf life. The export plan to Excel is the fourth design element. This allows the user to provide the output of the GUI software via Excel.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Accelerated Shelf-life Study

An accelerated shelf-life study was conducted for 88 days. Four different temperatures 70°F, 80°F, 90°F, and 100°F were used in this study. Four climate control chambers (Memmert, Engle, WI) were set to 70°F, 80°F, 90°F, and 100°F, respectively. The relative humidity was constant at 60% for each temperature variation. A total of 132 whole UHT milk tetra packs were used, 33 packs for each temperature (70°F, 80°F, 90°F, and 100°F). At 0, 12, 25, 32, 39, 46, 53, 60, 67, 74, and 88 days samples were analyzed for lipase and protease activity, pH, and L*, a*, b* color values over a period of 88 days. In total, 11 times samples were analyzed for pH, lipase activity, protease activity, and L*, a*, b* color values. Design of accelerated shelf life study is shown in Figure 7.

4.1.1 Lipase Activity and Protease Activity

Protease activity and lipase activity results showed that enzyme activity was low during UHT milk storage and seemed to have good quality. According to Humbert et al. 1997, the mean values of lipase activity for five winter milk samples, five summer milk samples, and some spring caprine milk were 0.06, 0.12, and 0.11µmol nitrophenol per min per ml, respectively. The lipase activity of UHT milk in this experiment seems lower than those values reported in the reference (Humber et al., 1997)[47]. Our results agreed with several references that protease activity and lipase activity in UHT milk were detected, such as research from Datta and Deeth (2003) and Choi and Jeon (1993) states [27, 52].

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Climate Control Chamber	Temp (°F)	R. Humidity	Sampling on an nth day	Analysis (triplicates)
1	70°F	60%	n = 0, 12, 25, 32, 39, 46, 53, 60, 67, 74, 88	pH Lipase activity Protease activity Color in L, a, b values
2	80°F			
3	90°F			
4	100°F			

Figure 7: Design of Accelerated Shelf Life Study

In Figure 8, protease activity results do not uniformly show an increasing or decreasing trend for 70°F, 80°F, 90°F, and 100°F temperature, and there is no clear separation between the curves for 70°F, 80°F, 90°F, and 100°F temperatures.

In Figure 9, lipase activity results do show a slightly decreasing trend for 70°F, 80°F, 90°F, and 100°F temperatures, but there is no clear separation between the curves for 70°F, 80°F, 90°F, and 100°F temperatures.

4.1.2 pH Value of Milk

The pH of UHT milk was measured using an Oakton pHTestr 30 Waterproof Pocket Tester. The result of the pH value of milk showed that there was a significant decrease in pH value at 70°F, 80°F, 90°F, and 100°F using linear regression analysis (Table 6). The correlation coefficient of the linear regression curve was high. Analysis of Covariance (ANCOVA) showed that the decreasing pH rates under different temperature conditions are different.

Hydrolysis of lipid by lipase in UHT whole milk to form free fatty acids is why pH decreases. The activity of lipase was temperature dependent. Some lipase seems to have the highest activity around 37°C (98.6 °F)[53]. Thus, the lipase activity of UHT milk at different temperatures from low to high seems to be in the following order: 70°F < 80°F < 90°F < 100°F. The pH of UHT milk decreased the most at 100°F. A decrease in pH of UHT milk during storage at room temperature and/or elevated temperatures has been reported by Celestino et al., (1997), and our result agreed with the reference [54].

In Figure 10, pH results do show a decreasing trend for 70°F, 80°F, 90°F, and 100°F temperatures, but there is no clear separation between the curves for 70°F, 80°F, 90°F, and 100°F temperatures.

Table 1: Protease activity values of UHT milk stored at 70°F, 80°F, 90°F, and 100°F.

Days	70°F	80°F	90°F	100°F
0	0.00153	0.00153	0.00153	0.00153
12	0.00435	0.00192	0.00098	0.00308
25	0.0016	0.00837	0.0041	0.01477
32	0.00085	0.0014	0.00161	0.00067
39	0.00062	0.00189	0.00109	0.00231
46	0.00124	0.0016	0.00127	0.0027
53	0.00015	0.00506	0.00349	0.004
60	0.00181	0.00029	0.00011	0.0003
67	0.00072	0.00108	0.00097	0.00089
74	0.00026	0.00076	0.00917	0.00317
88	0.00244	0.00263	0	0.00264

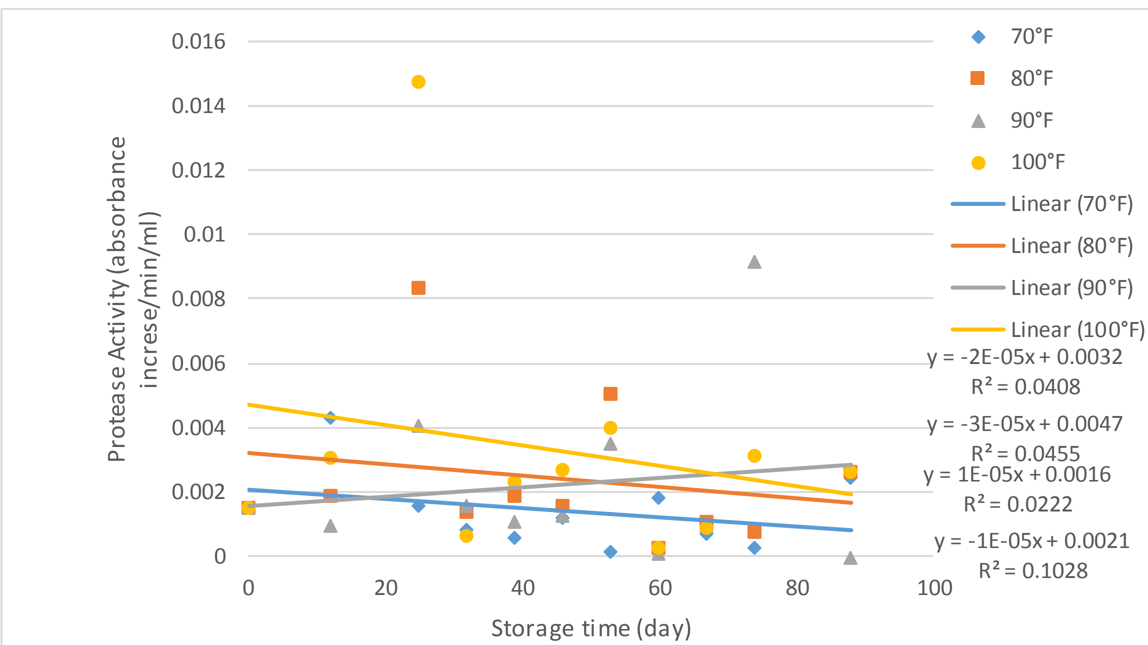

Figure 8: Protease activity of UHT milk stored at 70°F, 80°F, 90°F, and 100°F.

Table 2: Linear regression analysis of Protease activity value of UHT milk and storage time.

	70°F	80°F	90°F	100°F
Correlation Coefficient	0.321	0.202	0.587	0.213
alpha=0.05	0.497	0.497	0.497	0.497
alpha=0.01	0.658	0.658	0.658	0.658
df=n-1	10	10	10	10
P-value	> 0.05	> 0.05	< 0.05	>0.05
Significance	Not significant	Not significant	Not significant	Not significant

Table 3: Lipase activity values of UHT milk stored at 70°F, 80°F, 90°F and 100°F.

Days	70°F	80°F	90°F	100°F
0	0.03526	0.03526	0.03526	0.03526
12	0.03424	0.0312	0.02621	0.02855
25	0.04069	0.03436	0.03393	0.04175
32	0.04624	0.0333	0.02864	0.03586
39	0.03248	0.02969	0.03453	0.0347
46	0.0263	0.02691	0.02641	0.02891
53	0.01461	0.00919	0.01339	0.01588
60	0.02326	0.02353	0.02359	0.0273
67	0.02259	0.02239	0.02103	0.02291
74	0.02417	0.02302	0.01835	0.01859
88	0.02141	0.02025	0.02325	0.02072

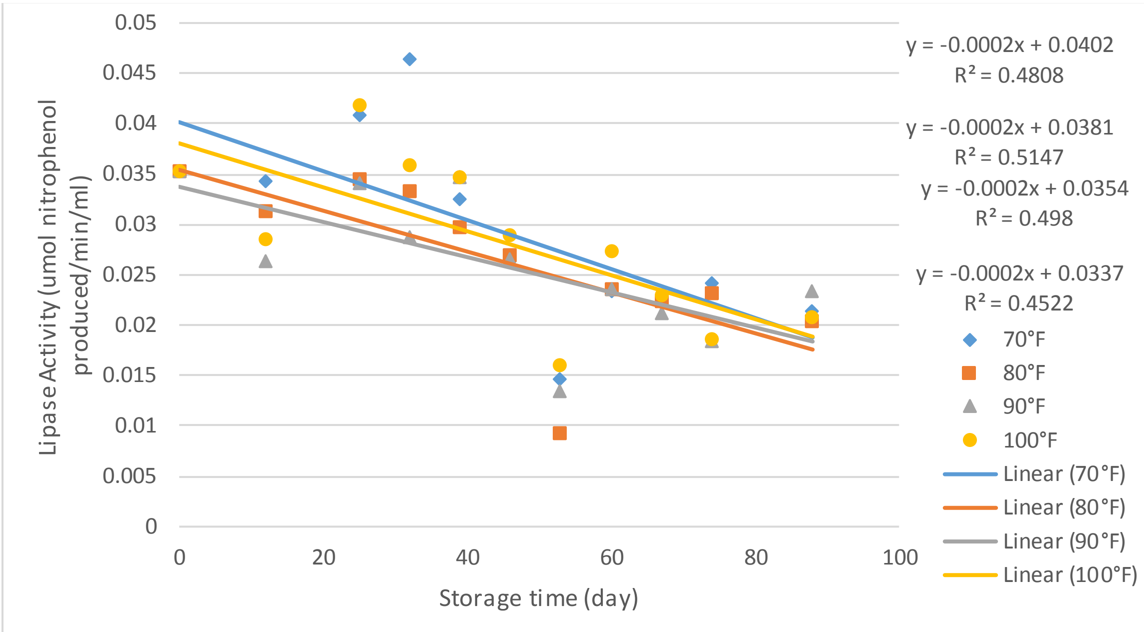

Figure 9: Lipase activity of UHT milk stored at 70°F, 80°F, 90°F, and 100°F.

Table 4:Linear regression analysis of Protease activity value of UHT milk and storage time.

	70°F	**80°F**	**90°F**	**100°F**
Correlation Coefficient	0.693	0.706	0.672	0.717
alpha=0.05	0.497	0.497	0.497	0.497
alpha=0.01	0.658	0.658	0.658	0.658
df=n-1	10	10	10	10
P-value	< 0.01	< 0.01	< 0.01	< 0.01
Significance	Not significant	Not significant	Not significant	Not significant

Table 5: pH values of UHT milk stored at 70°F, 80°F, 90°F, and 100°F.

Days	70°F	80°F	90°F	100°F
0	6.67	6.67	6.67	6.67
25	6.61	6.61	6.6	6.65
32	6.7	6.67	6.65	6.61
39	6.61	6.61	6.59	6.55
46	6.61	6.58	6.57	6.54
53	6.59	6.57	6.54	6.45
60	6.58	6.55	6.53	6.46
67	6.58	6.55	6.49	6.44
74	6.60	6.59	6.56	6.48
88	6.57	6.55	6.51	6.43

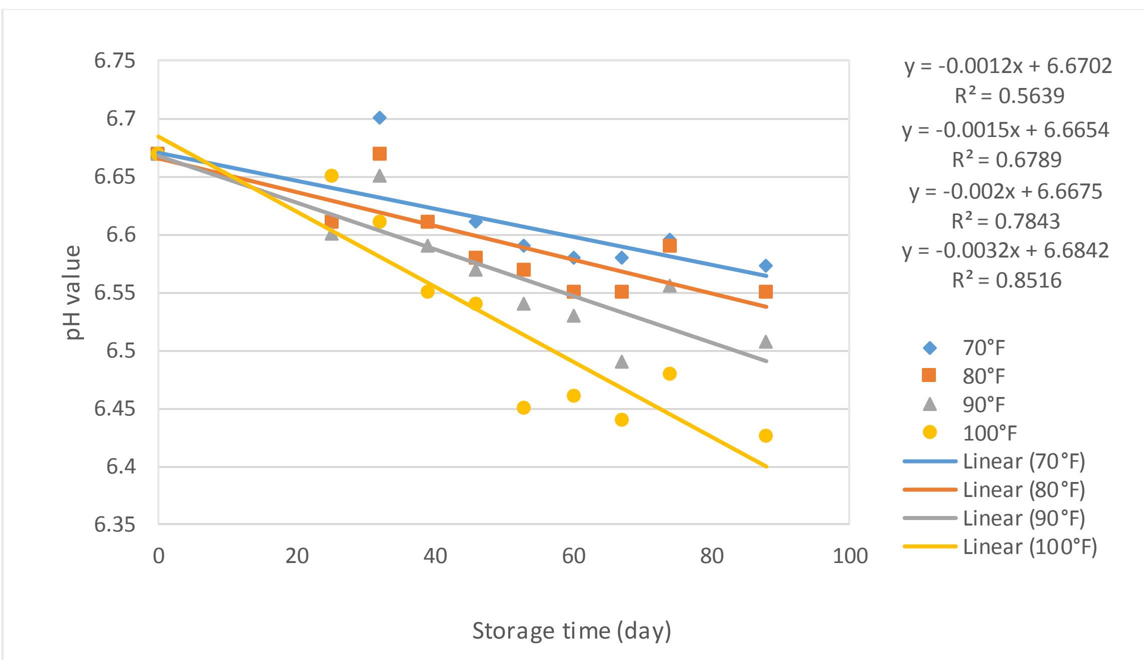

Figure 10: pH value of UHT milk stored at 70°F, 80°F, 90°F, and 100°F.

Table 6: Linear Regression analysis of pH value of UHT milk and storage time.

	70°F	80°F	90°F	100°F
Correlation Coefficient	0.751	0.824	0.886	0.923
alpha=0.05	0.521	0.521	0.521	0.521
alpha=0.01	0.685	0.685	0.685	0.685
df	9	9	9	9
P-value	< 0.01	< 0.01	< 0.01	< 0.01
Significance	Highly significant	Highly significant	Highly significant	Highly significant

4.1.3 Color of Milk

The colorimeter was used to calculate the L*, a*, and b* color values of the UHT milk. Hunter L* color value measures the change of white and blackness, Hunter a* color value measures the difference between the red and green color components (+ red, - green), and b* color value measures the differences between the yellow and blue color components (+ yellow, - blue). Using linear regression analysis, UHT milk L*, a*, and b* color values showed that:

1. No significant change of L* value with the storage time at 70°F, 80°F, 90°F, and 100°F (Figure 11).
2. Significantly increased a* value with the storage time at 70°F, 80°F, 90°F, and 100°F (Figure 12).
3. Significantly increased b* value with the storage time at 100°F, while there was no significant change of b* value with the storage time at 70°F, 80°F, 90°F (Figure 13).

In Figure 11, L* color values do not show uniformly increasing or decreasing trends for 70°F, 80°F, 90°F, and 100°F temperatures, and there is no clear separation between the curves for 70°F, 80°F, 90°F, and 100°F temperatures.

In Figure 12, a* color values do show a uniformly increasing trend for 70°F, 80°F, 90°F, and 100°F temperatures, and there is a clear separation between the curves for 70°F, 80°F, 90°F, and 100°F temperatures.

In Figure 13, b* color values do show an increasing trend for 70°F, 80°F, 90°F, and 100°F temperatures, but there is no clear separation between the curves for 70°F, 80°F, 90°F, and 100°F temperatures.

Our results agreed with previous research that a* and b* color of UHT milk increased during storage [55]. For a* color value, there is a significant difference among the four temperature treatments. a* color value increased significantly during the experimental time from day 0 to day 88.

Table 7: L* color value values of UHT milk stored at 70°F, 80°F, 90°F, and 100°F.

Day	70°F	80°F	90°F	100°F
0	90.17667	90.17667	90.17667	90.17667
12	92.05333	92.25	92.20333	92.25
25	91.73333	91.60667	91.68333	91.45667
32	91.56	91.78	91.72667	91.36333
39	91.70333	90.5	91.58667	90.97667
46	90.07667	89.60333	91.07333	87.86333
53	89.12333	88.65333	88.64333	89.22667
60	90.73333	91.94667	90.16333	90.45
67	91.6	91.43333	90.94333	90.42667
74	91.88	91.76667	91.37667	90.32333
88	91.59933	91.42333	90.97533	89.63667

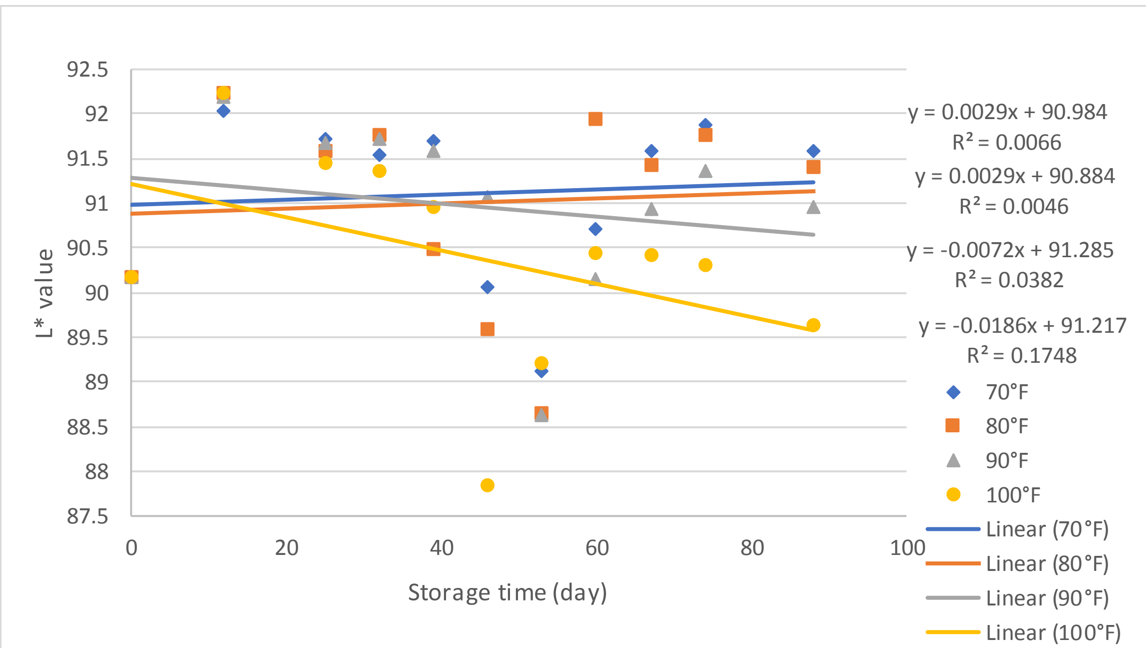

Figure 11: Change of L* color value of UHT milk stored at 70°F, 80°F, 90°F, and 100°F.

Table 8: Linear Regression analysis of L* color value of UHT milk and storage time.

	70°F	80°F	90°F	100°F
Correlation Coefficient	0.281	0.274	0.189	0.623
alpha=0.05	0.549	0.549	0.549	0.549
alpha=0.01	0.715	0.715	0.715	0.715
df=n-1	8	8	8	8
P-value	> 0.05	> 0.05	> 0.05	< 0.05
Significance	Not significant	Not significant	Not significant	Significant

Table 9: a* color value values of UHT milk stored at 70°F, 80°F, 90°F, and 100°F.

Day	70°F	80°F	90°F	100°F
0	-2.20333	-2.20333	-2.20333	-2.20333
12	-2.14333	-2.10333	-2.05	-1.82333
25	-2.10667	-2.06333	-1.93333	-1.63333
32	-2.07	-2.01333	-1.85667	-1.38667
39	-2.05667	-2.06167	-1.82333	-1.51333
46	-2.12	-2.1	-1.85	-1.85333
53	-2.15	-2.12667	-2.03667	-1.61333
60	-2.13333	-1.89333	-1.75333	-1.21333
67	-2.07333	-2.02667	-1.75	-1.01333
74	-2.16	-2.02	-1.7	-0.97667
88	-2.195	-2.04367	-1.67667	-0.89367

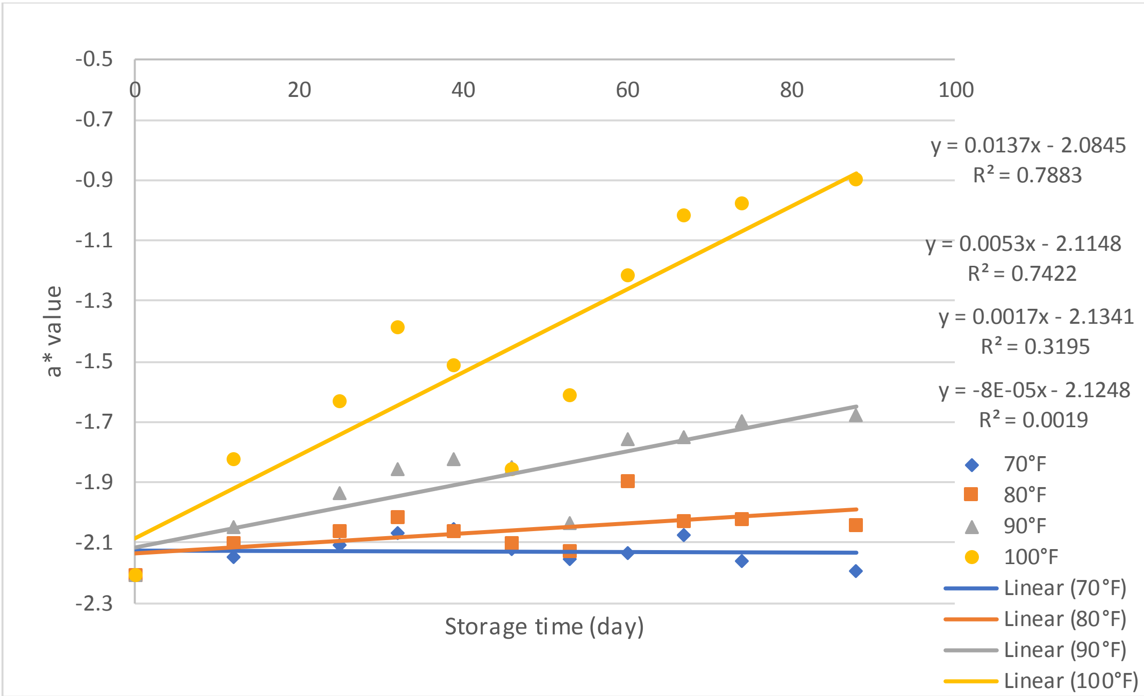

Figure 12: Change of a* color value of UHT milk stored at 70°F, 80°F, 90°F, and 100°F.

Table 10: Linear Regression analysis of a* color value of UHT milk and storage time.

	70°F	**80°F**	**90°F**	**100°F**
Correlation Coefficient	0.044	0.565	0.862	0.888
alpha=0.05	0.549	0.549	0.549	0.549
alpha=0.01	0.715	0.715	0.715	0.715
df	8	8	8	8
P-value	> 0.05	<0.05	< 0.01	< 0.01
Significance	Not significant	Significant	Highly significant	Highly significant

Table 11: b* color value values of UHT milk stored at 70°F, 80°F, 90°F, and 100°F.

Day	70°F	80°F	90°F	100°F
0	4.710	4.710	4.710	4.710
12	6.213	6.497	6.710	7.237
25	6.393	6.363	6.877	7.667
32	6.200	6.667	7.177	8.353
39	6.383	5.293	7.183	8.050
46	4.380	4.473	6.853	4.850
53	3.627	3.353	4.207	7.250
60	5.307	7.333	6.383	9.180
67	6.480	6.673	7.443	9.810
74	6.383	6.870	7.830	10.357
88	6.274	6.763	7.970	10.973

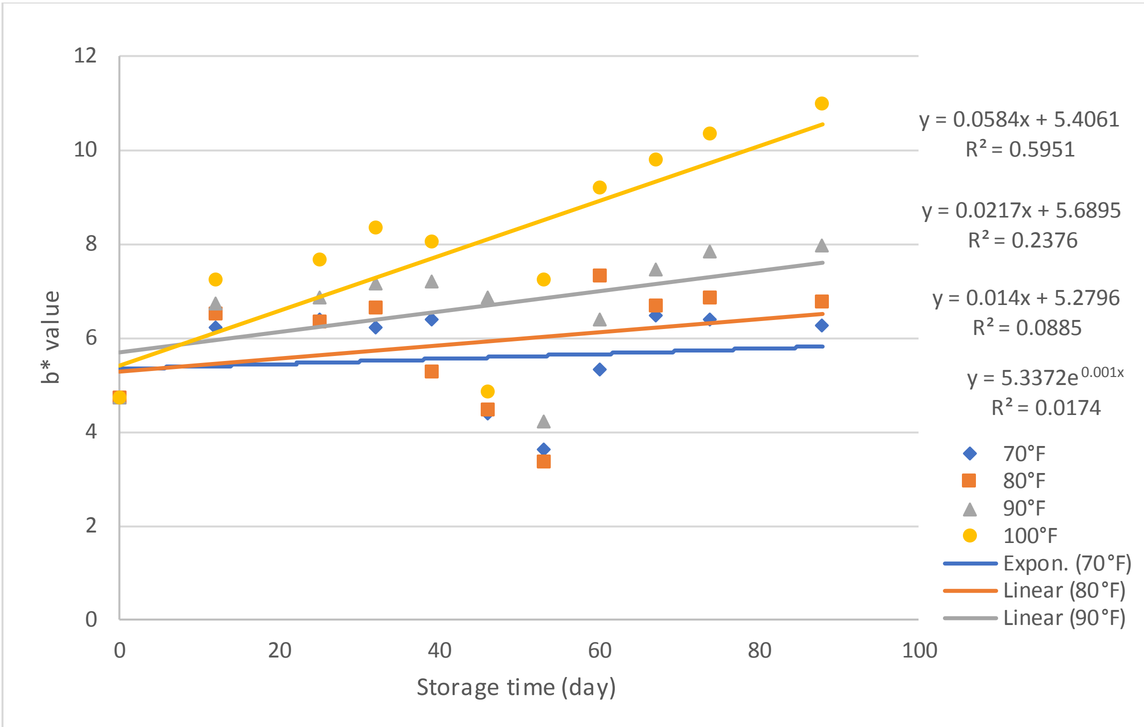

Figure 13: Change of b* color value of UHT milk stored at 70°F, 80°F, 90°F, and 100°F.

Table 12: Linear Regression analysis of b* color value of UHT milk and storage time.

	70°F	**80°F**	**90°F**	**100°F**
Correlation Coefficient	0.153	0.297	0.487	0.771
alpha=0.05	0.549	0.549	0.549	0.549
alpha=0.01	0.715	0.715	0.715	0.715
df	8	8	8	8
P-value	> 0.05	<0.05	< 0.01	< 0.01
Significance	Not significant	Not significant	Not significant	Highly significant

4.1.4 Selection of Milk Spoilage Parameter for Model

Changes in enzymatic (lipase and protease) activities in UHT milk are hard to detect even after ten weeks of storage at elevated temperatures. The color change provided a better indication of chemical changes in UHT milk. a* color values provided the best correlation coefficient from the accelerated shelf life analysis; hence, it is used as the prediction model's parameter.

4.2 Physical Simulation of Supply Chain Scenarios

Two physical simulations were designed based on the UHT milk supply chain's actual transportation and storage conditions. In the first physical simulation, only 70°F, 80°F, 90°F, and 100°F temperature values were used. While in the second physical simulation, realistic temperature profiles were used from historical data, and temperature conditions were changed every 3-6 hours. In both the physical simulations, a* color values were measured at the start of the experiment and at the end of the experiment.

4.2.1 Physical Simulation 1

In this physical simulation, eight scenarios were conducted for 45 days with four different temperatures 70°F, 80°F, 90°F, and 100°F shown in Table 13. Scenarios of the experiment considered temperature condition in the warehouse, wait time for delivery, customer pick up, temperature control storage, elevated room temperature, and customer consumption based on the details obtained from historical records and interviews with personnel in receiving and storage facilities. Humidity was standardized to 60%. A total of 18 whole UHT milk tetra packs were used with the same manufacturing date, two packs for each scenario. At the start of the experiment, a* color value was measured for two UHT milk tetra packs. The mean of the two readings was taken as the baseline value of the UHT milk. The

Table 13: Supply chain scenarios used in physical simulation 1.

Scenario	Warehouse		Wait for delivery		Warehouse		Wait for delivery		Warehouse		Ship pick up		Temp-control Storage		Near engine room		Customer pick up	
	Temp(F)	(days)	Temp(F)	(days)	Temp(F)	(days)	Temp(F)	(days)	Temp(F)	(days)	Temp(F)	(days)	Temp(F)	(days)	Temp(F)	days	Temp(F)	days
1	90	15	80	3	90	15	80	2			80	2	70	7			80	1
2	80	15	90	3	80	15	90	2			90	2	70	7			90	1
3	100	15	90	3	100	15	90	2			90	2	70	7			90	1
4	100	30	90	2							80	2	70	10			90	1
5	80	30	90	2							80	2	70	10			90	1
6	90	30	80	2							90	2	70	10			80	1
7	100	25	90	2	100	5					90	2			100	10	90	1
8	90	25	80	2	90	5					80	2			100	10	80	1

baseline a* color value was -2.067. Then experiments were conducted using 16 UHT milk tetra packs for 45 days, and at the end of the experiments, a* color value was measured for each scenario. As we used two UHT milk tetra packs for each scenario, the two-reading mean was taken as the a* color value for each scenario shown in Table 15.

To understand each activity, scenario 2 is explained in Table 14.

In scenario 2, milk is ordered from the milk producer and received by the customer warehouse. After that, the sequence of activities are described as follows:

1. The first activity was the duration of milk stored in the warehouse. In this scenario, milk was stored for 15 days.
2. The second activity was the waiting period for delivery, where milk moved out of the warehouse and was placed outside on the dock for delivery. But due to a supply chain change or for similar reasons, the delivery of milk was canceled for the time being, and thus the milk was moved back into the warehouse.
3. The third activity was again the storage duration of milk in the warehouse for 15 days.
4. The fourth activity was again where milk waited for customer pick up for two days.
5. The fifth activity was the customer pickup of the milk.
6. After that, the sixth activity was milk storage in the temperature-controlled chamber, and in this scenario, it stays for seven days.
7. The last activity was milk consumption.

Other scenarios were designed similarly by considering different temperatures and stay duration conditions at the warehouse, wait for delivery, customer pick up, temperature-controlled storage, and elevated room temperature. At the end of the experiment the final a* color value is calculated for all the scenarios.

Table 14: Physical simulation 1 - Scenario 2

Sr. No.	Activities	Temp (F)	Days
1	Warehouse	80	15
2	Wait for delivery	90	3
3	Warehouse	80	15
4	Wait for delivery	90	2
5	Pick up by customer	90	2
6	Temp-Control storage	70	7
7	Milk consume	90	1

Table 15: Final a* color values for physical simulation 1 scenarios.

Scenario	a* Color Values
1	-1.886
2	-1.971
3	-1.595
4	-1.62
5	-2.022
6	-1.869
7	-1.471
8	-1.766

4.2.2 Physical Simulation 2

In this physical simulation, three scenarios were conducted for 56 days with a realistic temperature profile shown in Table 16. Historical data was used, and temperature conditions were changed every 3-6 hours. Humidity was standardized to 60%. A total of eight whole UHT milk tetra packs were used with the same manufacturing date, two packs for each scenario. At the start of the experiment, a* color value was measured for two UHT milk tetra packs, and the mean of the two readings was taken as the UHT milk's baseline value. The baseline a* color value was -1.718. Then experiments were conducted using 6 UHT milk tetra packs for 56 days, and at the end of the experiments, a* color value was measured for each scenario. As we used two UHT milk tetra packs for each scenario, the mean of the two-readings were taken as the a* color value for each scenario shown in Table 17.

In each scenario, three nodes were used: 1) Logan, Utah (milk producer) 2) Tracy, CA (Customer's warehouse) 3) Miami, FL (Customer's warehouse). The sequence of events for three scenarios were described as follows:

1. The milk was transported from milk producer Logan, UT, to Tracy, CA, over a period of 3 days. The milk was carried in a temperature-controlled vehicle at an optimal temperature of 70°F.
2. Milk was stored in the warehouse at Tracy, CA, for 21 days.
3. Then milk traveled to Miami, FL, from Tracy, CA over a period of 3 days. It was carried in a temperature-controlled vehicle at an optimal temperature of 70°F.
4. Milk stored at the warehouse in Miami, FL, for 29 days.
5. Milk was consumed.

In all three scenarios, the milk stays for 21 days at the warehouse in Tracy, CA, and 29 days at the warehouse in Miami, FL. For this period, the historical temperature data were used and obtained from the Weather Underground site [12]. For the Tracy, CA warehouse, late spring historical data from 20 April 2019 to 11

Table 16: Supply Chain condition for physical simulation 2.

Scenarios	Trasportation Logan UT to Tracy CA		Warehouse Tracy CA		Trasportation Tracy CA to Miami FL		Warehouse Miami FL	
	Temp (F)	Days	Temp (F)	Days	Temp (F)	Days	Temp (F)	Days
1	70	3	3 Hrs Variable	21	70	3	3 Hrs Variable	29
2	70	3	70	21	70	3	3 Hrs Variable	29
3	70	3	70	21	70	3	6 Hrs Variable	29

Table 17: Final a* color values for physical simulation 2 scenarios.

Scenario	a* Color Values
1	-1.4912
2	-1.53
3	-1.5187

May 2019 was simulated, and for the Miami, FL warehouse, summer historical data from 20 June 2019 to 19 July 2019 was simulated.

Highlights of physical simulation 2 – scenario 1:

1. This scenario emulates 56 days (7 weeks) of the supply chain.
2. All the transportation conditions were carried out at 70°F.
3. Temperature from historical data emulates with 3-hour intervals in the warehouse condition of Tracy, CA, and Miami, FL (9 AM-12 PM, 12 PM-3 PM, 3 PM-6 PM, and 6 PM-9 PM).
4. Temperature from 9 PM to 9 AM stayed the same in the warehouse condition because there is significantly less fluctuation in the temperature at night between 9 PM to 9 AM.
5. Humidity is standardized to 60%.

In physical simulation 2, the difference between scenario 1 and scenario 2 is that the Tracy, CA warehouse was kept at 70°F (Assumed temperature-controlled warehouse) for 21 days. In scenario 3, the temperature of Tracy, CA warehouse was kept at 70°F (Assumed temperature-controlled warehouse) for 21 days, and temperature from historical data emulates with the interval of 6 hours in Miami's warehouse condition in Florida. At the end of the experiment, the final a* color value is calculated for all three scenarios.

4.3 Predictive Model Results

The iterative piecewise linear model was used to calculate the predicted a* color value for all the scenarios. Step by step calculation using an iterative piecewise linear model for scenario 2 from physical simulation 1 is shown below:

Table 18: Physical simulation 1 - scenario 2.

Sr. No.	Activities	Temp (F)	Days
1	Warehouse	80	15
2	Wait for delivery	90	3
3	Warehouse	80	15
4	Wait for delivery	90	2
5	Pick up by the customer	90	2
6	Temp-Control storage	70	7
7	Milk consume	90	1

$a_0^* = -2.067$

$a_1^* = a_0^* + \beta_1 t_1 = (-2.067) + (0.0017*15) = -2.0415$

$a_2^* = a_1^* + \beta_2 t_2 = (-2.0415) + (0.0053*3) = -2.0256$

$a_3^* = a_2^* + \beta_3 t_3 = (-2.0256) + (0.0017*15) = -2.0001$

$a_4^* = a_3^* + \beta_4 t_4 = (-2.0001) + (0.0053*2) = -1.9895$

$a_5^* = a_4^* + \beta_5 t_5 = (-1.9895) + (0.0053*2) = -1.9789$

$a_6^* = a_5^* + \beta_6 t_6 = (-1.9789) + (0.00008*7) = -1.978$

$a_7^* = a_6^* + \beta_7 t_7 = (-1.97834) + (0.0053*1) = -1.973$

Likewise, using the iterative piecewise linear model, the predicted a* color value measured for all the scenarios for physical simulation 1 and 2 shown in Table 19 and Table 20.

4.3.1 Accuracy of the Iterative Piecewise Linear Model

The predicted model's accuracy was validated using the Mean Absolute Percentage Error (MAPE) performance metric. MAPE is a broadly accepted function in statistics and forecasting, in which the lower percentage error is, the better the model. Its formula is:

$$MAPE = \sum_{i=1}^{N} \left[{|A - F|}/{A} \right] * {100}/{N}$$

Where, A = actual value, F = forecast or predicted value, N = total number of scenarios. Table 21 and Table 22 show the absolute deviation errors obtained for each of the predicted a* color values from the model compared values to the actual observed values at each scenario.

Table 19: Actual and predicted a* value of physical simulation 1.

Scenario	Actual a* Values	Predicted a* Values
1	-1.886	-1.893
2	-1.971	-1.973
3	-1.595	-1.613
4	-1.62	-1.635
5	-2.022	-1.995
6	-1.869	-1.891
7	-1.471	-1.492
8	-1.766	-1.762

Table 20: Actual and predicted a* value of physical simulation 2

Scenario	Actual a* Values	Predicted a* Values
1	-1.4912	-1.4861
2	-1.53	-1.525
3	-1.5187	-1.5342

Table 21: Actual and predicted a* value and absolute deviation error of physical simulation 1.

Scenario	Actual a* Values	Predicted a* Values	Absolute Deviation Error
1	-1.886	-1.893	0.007
2	-1.971	-1.973	0.002
3	-1.595	-1.613	0.018
4	-1.62	-1.635	0.015
5	-2.022	-1.995	0.027
6	-1.869	-1.891	0.022
7	-1.471	-1.492	0.021
8	-1.766	-1.762	0.004

Table 22: Actual and predicted a* value and absolute deviation error of physical simulation 2

Scenario	Actual a* Values	Predicted a* Values	Absolute Deviation Error
1	-1.4912	-1.4861	0.005
2	-1.53	-1.525	0.005
3	-1.5187	-1.5342	0.015

Mean Absolute Percentage Error (MAPE) calculated by inserting obtained absolute deviation errors for physical simulation 1 and 2. MAPE equation shows a 0.84% prediction error for physical simulation 1 and 0.92% prediction error for physical simulation 2. These low error values validate the high accuracy of the predictive model.

In Figure 14 and Figure 15, it can be seen that the curves for actual and predicted values are barely separated; in fact, they appear to be a single curve.

4.4 GUI Software for Supply Chain Manager

This section describes the iterative piecewise linear model findings into practical tools for the supply chain manager of UHT milk. Each plan is customized for a single route of the supply chain. For example, in physical simulation 1, the plan for scenario 1 will be prepared separately from scenario 2.

How to use GUI software shown in Figure 16:

1. Open the GUI software
2. The interface, shown in Figure 16, will load
3. Click on the location under "supply chain location"
4. Select the temperature for a selected location using the slider under "Temperature"
5. Select the stay duration for a selected location using the slider under "Time"
6. Repeat steps 3-5 for planned supply chain route
7. Click on "Estimate spoilage risk"
8. The boxes of "spoilage risk", "Days to delivery" and "Milk color trend" will update.

The GUI software conveys spoilage risk and days to spoilage of the UHT milk supply chain route. The GUI software gives the supply chain manager the chance to make changes to the plan which improves the shelf life. For example, the supply chain manager may decide that the UHT milk must spend less time at a specific warehouse that is not climate controlled or instruct to set transportation chamber at 70°F for a specific route.

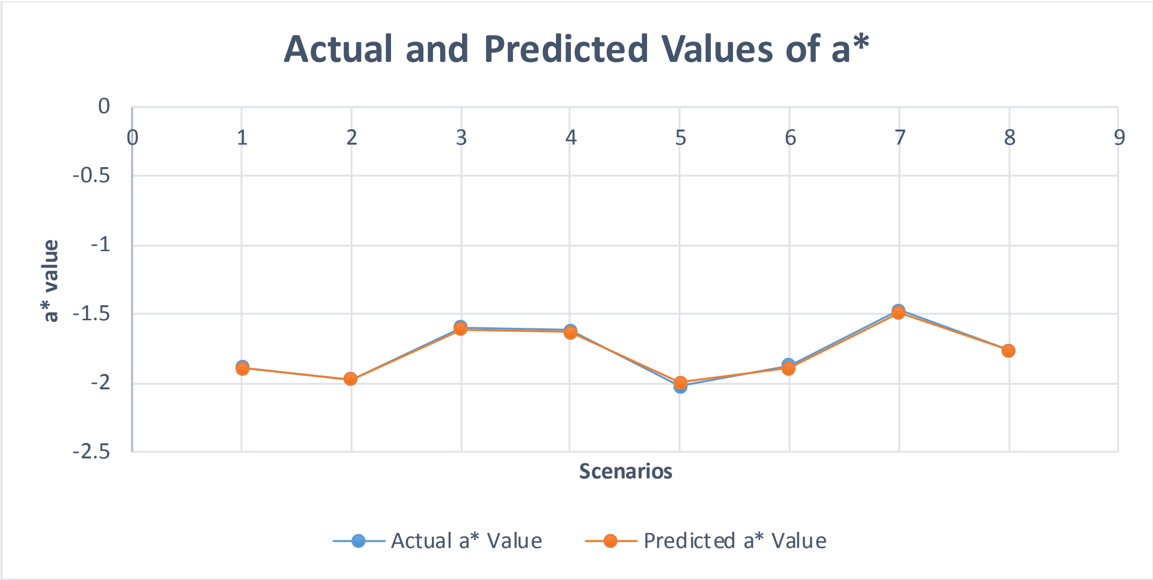

Figure 14: Actual and predicted values of a* of physical simulation 1

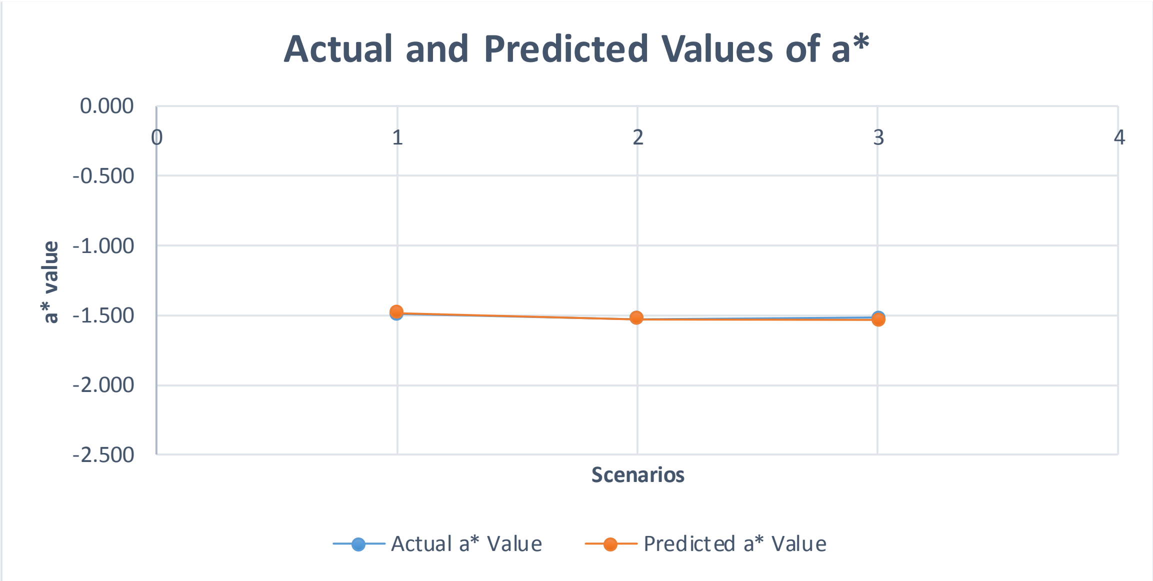

Figure 15: Actual and predicted values of a* of physical simulation 2

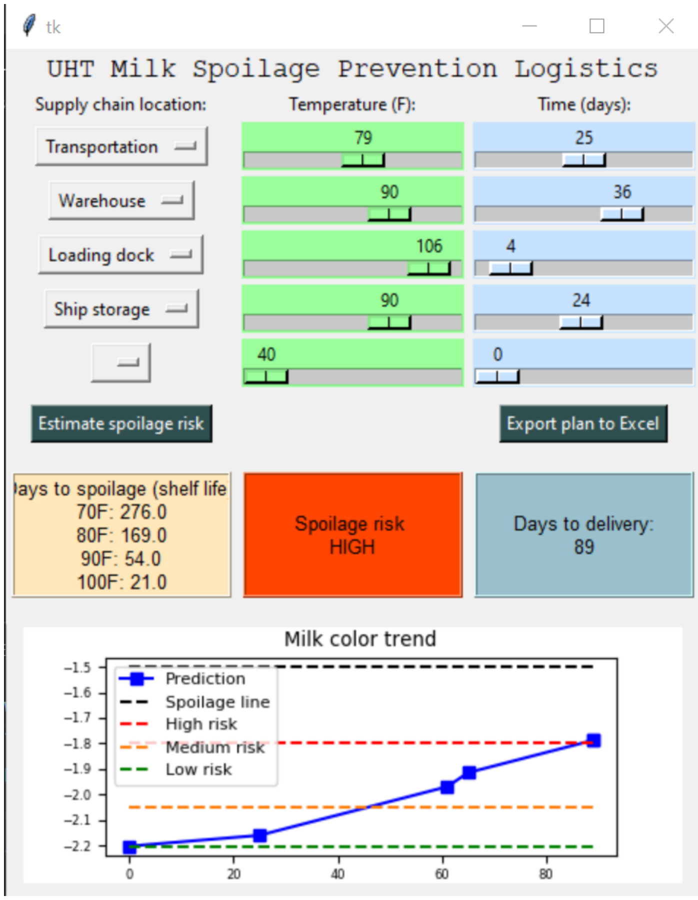

Figure 16: GUI Software

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Shelf stable food products are becoming increasingly popular in the last few years. Shelf stable food product ensures a long shelf life with good quality but there is no study which links shelf stable product to their supply chain factors. Supply chain factors are transportation condition, storage condition, temperature, and humidity. UHT milk is a shelf stable product with a planned shelf life of twelve months. In the past, studies have examined the shelf life of UHT milk with constant temperatures ranging from normal to extreme. However, there is no study on the realistic supply chain condition of UHT milk. This thesis presents a method to study the shelf life of UHT milk and predict shelf life given realistic supply chain conditions.

A mathematical iterative piecewise linear model was developed to predict the shelf life of UHT milk. This model takes into account the changes in the UHT milk color to characterize the spoilage and reduction of the shelf life. Based on the prediction model of UHT milk Graphical User Interface (GUI) was designed for supply chain managers.

Two Physical simulations were conducted using normal, extreme, and realistic weather conditions and calculated actual UHT milk color values. In the first physical simulation, only 70°F, 80°F, 90°F, and 100°F temperature values were used. While in the second physical simulation, realistic temperature profiles were used from historical data, and temperature conditions were changed every 3-6 hours. Then actual UHT milk color values were compared with the values obtained by mathematical iterative piecewise linear model. Mean absolute percentage error shows a 0.84% prediction error for physical simulation 1 and 0.92% prediction error for physical simulation 2.

The future work for this study can be summarized in two points:

- This study was conducted and analyzed on whole UHT milk; hence it is uncertain that this model will work for other UHT milk such as non-fat, reduced-fat, flavored, or chocolate UHT milk.
- One of the assumptions was the UHT milk color threshold of spoilage, which is uncertain. The actual value of the UHT milk color threshold of spoilage will help for the iterative piecewise linear prediction model.

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